Stokes Vector of Photon in the Decays $B^0 \to \rho^0\gamma$ and $B^0 \to K^*\gamma$

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Abstract

We consider a model for the decay $\overline{B^0} \to \rho^0\gamma$ in which the short-distance amplitude determined by the Hamiltonian describing $b \to d\gamma$ is combined with a typical long-distance contribution $\overline{B^0} \to D^+D^- \to \rho^0\gamma$. The latter possesses a significant dynamical phase which induces a CP-violating asymmetry $A_{\rm CP}$, as well as an important modification of the Stokes vector of the photon. The components S_1 and S_3 of the Stokes vector $\vec{S} = (S_1, S_2, S_3)$ can be measured in the decay $\overline{B^0} \to \rho^0\gamma^* \to \pi^+\pi^-e^+e^-$ where they produce a characteristic effect in the angular distribution $d\Gamma/d\phi$, ϕ being the angle between the $\pi^+\pi^-$ and e^+e^- planes. A similar analysis is carried out for the decays $\overline{B^0} \to \overline{K^*}\gamma$ and $\overline{B^0} \to \overline{K^*}\gamma^* \to \pi^+K^-e^+e^-$.

1 Introduction

We study in this paper a long-distance contribution to the decay $\overline{B^0} \to \rho^0\gamma$, which has the interesting feature of possessing a large dynamical phase. When added to the short-distance amplitude determined by the $b \to d\gamma$ penguin operator, this produces an asymmetry $A_{\rm CP}$ between $\Gamma(\overline{B^0} \to \rho^0\gamma)$ and $\Gamma(B^0 \to \rho^0\gamma)$. In addition, the presence of the long-distance component affects the polarization state (Stokes vector) of the photon. This effect can be measured in the decay $\overline{B^0} \to \rho^0e^+e^- \to \pi^+\pi^-e^+e^-$. An analogous effect on the Stokes vector occurs in the decay $\overline{B^0} \to \overline{K^*}\gamma$. The Stokes vector turns out to be very sensitive to the proposed long-distance contribution and thus may give more insight into the structure of the radiative decay amplitude.

The main contribution to the amplitude of the decay $\overline{B^0} \to \rho^0\gamma$ is believed to come from the effective Hamiltonian

$$H_{\rm eff} = \frac{G_F}{\sqrt{2}} V_{tb}V_{td}^* c_7 \mathcal{O}_7. \tag{1}$$

G_F is Fermi's constant, V_{ij} the CKM matix elements, c_7 the Wilson coefficient and $\mathcal{O}_7$ is the electromagnetic penguin operator

$$\mathcal{O}_7 = \frac{e}{8\pi^2}\, \overline{d}\, \sigma_{\mu\nu} m_b(1+\gamma_5)\, b\, F^{\mu\nu}. \tag{2}$$

The corresponding amplitude contains a parity conserving (magnetic) term and a parity violating (electric) term and can be written as [1]:

$$\mathcal{A}(\overline{B^0} \to \rho^0\gamma) = \frac{eG_F}{\sqrt{2}} \left(\epsilon_{\mu\nu\rho\sigma} q_1^\mu \epsilon_1^{*\nu} q_2^\rho \epsilon_2^{*\sigma} M_{\rm SD} + i\epsilon_1^{*\mu}\epsilon_2^{*\nu} \left(g_{\mu\nu} p\cdot q_1 - p_\mu q_{1\nu} \right) E_{\rm SD} \right), \tag{3}$$

where p is the momentum of the $\overline{B^0}$ meson, q_1 is the momentum of the photon and ϵ_1 its polarization vector, q_2 is the momentum of the ρ^0 meson and ϵ_2 its polarization vector. (The subscript SD denotes short-distance.)

Using the identity $\sigma_{\mu\nu} = \frac{i}{2}\epsilon_{\mu\nu\alpha\beta}\sigma^{\alpha\beta}\gamma_5$ it immediately follows that

$$E_{\rm SD} \equiv M_{\rm SD}. \tag{4}$$

Since only one weak phase is involved, this amplitude on its own produces no CP violation. The branching ratio is:

$$Br(\overline{B^0} \to \rho^0\gamma) = \frac{G_F^2\alpha}{16}\,\tau_{B^0}\, m_{B^0}^3 \left(1 - \frac{m_{\rho^0}^2}{m_{B^0}^2}\right)\left(|E_{\rm SD}|^2 + |M_{\rm SD}|^2\right), \tag{5}$$

where [1]

$$M_{\rm SD} = -V_{tb}V_{td}^{*}c_7\frac{m_b}{2\pi^2}\frac{T_1^{B^-\to\rho^-}(0)}{\sqrt{2}} \tag{6}$$

and $T_1^{B^-\to\rho^-}(0)$ is the form factor of the $B^- \to \rho^-$ transition due to the tensor current [6].

The decay $\overline{B^0} \to \rho^0\gamma$ possesses another observable: the Stokes vector, specifiying the polarization state of the photon. Conforming to the notation of Ref. [2], we rewrite the decay amplitude (3) in the general form

$$\mathcal{A}(\overline{B^0} \to \rho^0\gamma) = \frac{eG_F}{\sqrt{2}}\left(\epsilon_{\mu\nu\rho\sigma}q_1^\mu\epsilon_1^{*\nu}q_2^\rho\epsilon_2^{*\sigma}\mathcal{M} + \epsilon_1^{*\mu}\epsilon_2^{*\nu}\left(g_{\mu\nu}p\cdot q_1 - p_\mu q_{1\nu}\right)\mathcal{E}\right), \tag{7}$$

where $\mathcal{M} = M_{\rm SD} + \ldots$ and $\mathcal{E} = i(E_{\rm SD} + \ldots)$, the dots denoting further interaction terms to be introduced later. The polarization of the photon is defined by the density matrix ρ:

$$\begin{aligned}\rho &= \begin{pmatrix} |\mathcal{E}|^2 & \mathcal{E}^*\mathcal{M} \\ \mathcal{E}\mathcal{M}^* & |\mathcal{M}|^2 \end{pmatrix} \\ &= \frac{1}{2}\left(|\mathcal{E}|^2 + |\mathcal{M}|^2\right)\left(\mathbf{1} + \vec{S}\cdot\vec{\tau}\right),\end{aligned} \tag{8}$$

where $\vec{\tau}$ are the Pauli matrices and $\vec{S}$ is the Stokes vector. The components of the Stokes vector are according to Eq. (8):

$$\begin{aligned} S_1 &= \frac{2\,{\rm Re}(\mathcal{E}^*\mathcal{M})}{|\mathcal{E}|^2 + |\mathcal{M}|^2}, \\ S_2 &= \frac{2\,{\rm Im}(\mathcal{E}^*\mathcal{M})}{|\mathcal{E}|^2 + |\mathcal{M}|^2}, \\ S_3 &= \frac{|\mathcal{E}|^2 - |\mathcal{M}|^2}{|\mathcal{E}|^2 + |\mathcal{M}|^2}. \end{aligned} \tag{9}$$

The component S_2 describes the circular polarisation of the photon which has been discussed by Grinstein and Pirjol [3]. More interesting from our point of view are the components S_1 and S_3 which can be measured indirectly by studying the Dalitz pair process $\overline{B^0} \to \rho^0\gamma^* \to \rho^0 e^+e^-$.

If the short-distance amplitude is the only contribution there is no CP asymmetry ($A_{\rm CP}=0$) and the photon is purely left-handed polarized, the Stokes vector reducing to the trivial form ($S_{1,3}=0,\ S_2=-1$).

In the next Section, we introduce an extra contribution to the $\overline{B^0}\to\rho^0\gamma$ amplitude that carries not only a different weak phase but a non-trivial dynamical (strong) phase, thereby generating non-vanishing values for the observables $A_{\rm CP}$, S_1 and S_3.

2 A long-distance contribution to $\overline{B^0}\to\rho^0\gamma$

We consider the long-distance contribution to the decay $\overline{B^0}\to\rho^0\gamma$ depicted by the triangle graphs in Fig. (1) with D^+D^- mesons as intermediate states[1]. The amplitude is calculated by analogy to the pion-loop model used for the decay $K_S\to\gamma\gamma^*$, discussed in detail in Ref. [4]. In such a model, based on minimal electromagnetic coupling, both real and imaginary parts of the amplitude are finite and calculable. Using dimensional regularization the gauge-invariant amplitude for the three graphs (triangle + crossed + sea-gull) is purely electric:

$$\mathcal{A}_{\rm LD}=\frac{eG_F}{\sqrt{2}}i\epsilon_1^{*\mu}\epsilon_2^{*\nu}\left(g_{\mu\nu}p\cdot q_1-p_\mu q_{1\nu}\right)E_{\rm LD}, \tag{10}$$

where

$$E_{\rm LD}=-V_{cb}V_{cd}^*\frac{2f_{\rho^0D^+D^-}g_{B^0D^+D^-}}{(4\pi)^2m_{D^+}^2}F(m_{B^0}^2,m_{\rho^0}^2) \tag{11}$$

and [7]

$$\begin{aligned}
F(m_{B^0}^2,m_{\rho^0}^2) &= -\frac{1}{2(a-b)}+\frac{1}{(a-b)^2}\left[\frac{f_a-f_b}{2}+b\,(g_a-g_b)\right], \qquad (12)\\
f_a &= -\left(\ln\left(\sqrt{a}+\sqrt{a-1}\right)-i\frac{\pi}{2}\right)^2,\\
g_a &= \sqrt{\frac{a-1}{a}}\left(\ln\left(\sqrt{a}+\sqrt{a-1}\right)-i\frac{\pi}{2}\right),\\
f_b &= \arcsin^2\left(\sqrt{b}\right),\\
g_b &= \sqrt{\frac{1-b}{b}}\arcsin\left(\sqrt{b}\right),\\
a &= \frac{m_{B^0}^2}{4m_{D^+}^2},\\
b &= \frac{m_{\rho^0}^2}{4m_{D^+}^2}.
\end{aligned}$$

[1]Similar graphs have been considered in connection with the long-range contribution to $B^0\to\gamma\gamma$; see, for example, Ref. [4]. It may be mentioned that long-distance effects of operators containing $\overline{c}c$ currents in charmless B-decays have also been discussed under the appelation *charming penguins* [5]. We are not aware of a discussion of the radiative decays $\overline{B^0}\to\rho^0\gamma$ ($\overline{B^0}\to\overline{K^*}\gamma$) along these lines.

In this model there are only two parameters left: the coupling constants $g_{B^0 D^+ D^-}$ and $f_{\rho^0 D^+ D^-}$. The coupling $g_{B^0 D^+ D^-}$ is determined by data ($Br(\overline{B^0} \to D^+ D^-) = 2.46 \times 10^{-4}$) [8]. For $f_{\rho^0 D^+ D^-}$ we use the vector dominance hypothesis, which implies $f_{\rho^0 D^+ D^-} = \frac{1}{2} f_{\rho^0 \pi^+ \pi^-}$. Using the empirical value $f^2_{\rho\pi^+\pi^-}/4\pi \approx 2.5$, we thus have

$$g_{B^0 D^+ D^-} = \frac{4}{G_F \, |V_{cb} V^*_{cd}|} \sqrt{\frac{2\pi m_{B^0}}{\tau_{B^0} \sqrt{1 - \frac{4 m^2_{D^+}}{m^2_{B^0}}}}} \sqrt{Br(\overline{B^0} \to D^+ D^-)}, \tag{13}$$

$$f_{\rho^0 D^+ D^-} = \frac{1}{2} f_{\rho\pi^+\pi^-} \approx \sqrt{2.5\pi}. \tag{14}$$

A comparison of the penguin amplitude with the above long-distance contribution reveals serveral interesting features.

(a) The two amplitudes have different CKM factors, hence different weak phases. In addition, the long-distance part has a large absorptive part, producing a significant strong phase:

$$\delta_{\rm dyn} = \arctan \left(\frac{\mathrm{Im}\left[F(m^2_{B^0}, m^2_{\rho^0})\right]}{\mathrm{Re}\left[F(m^2_{B^0}, m^2_{\rho^0})\right]} \right) \approx 97^\circ. \tag{15}$$

This opens the way to a non-zero CP-violating asymmetry $A_{\rm CP}$.

(b) The long-distance component is quite sizeable in comparison to the short-distance amplitude. Taking the estimates in Eqs. (14) and (13) at face value,

$$\frac{\Gamma_{\rm LD}}{\Gamma_{\rm SD}} \approx 30\%. \tag{16}$$

(c) The long-distance amplitude generated by the D^+D^- intermediate state is purely electric, in contrast to the equality of $E_{\rm SD}$ and $M_{\rm SD}$ (Eq. (4)). This implies that the Stokes vector component S_3 will be non-zero. The existence of the strong phase $\delta_{\rm dyn}$ also means that the component S_1 will be different from zero. Thus, we can expect non-trivial effects associated with $S_{1,3} \neq 0$ in the Dalitz pair reaction $\overline{B^0} \to \rho^0 \gamma^* \to \rho^0 e^+ e^-$.

The amplitude $\mathcal{A}_{\rm LD}$ given by Eqs. (10) - (12), is based on minimal electromagnetic coupling, and serves as a convenient reference value for the long-range contribution to $\overline{B^0} \to \rho^0 \gamma$, possessing finite real and imaginary parts. The composite nature of the D-meson implies that there will be other intermediate states such as DD^*, D^*D^* etc., as well as possible form factor effects in the $D\overline{D}$ contribution. Data on B^0 decays suggest that the DD^*, D^*D^* final states are dominantly $CP = +1$ [9], the same as for D^+D^-, implying that the effect of these intermediate states on $\overline{B^0} \to \rho^0 \gamma$ is mainly in the electric amplitude $\mathcal{E}$. In what follows we simulate the total long-distance amplitude by using an expression of the form $\mathcal{A}_{\rm LD} = \xi \mathcal{A}_{\rm LD}(D^+D^-)$, allowing the parameter ξ to vary in the range $-1 \leq \xi \leq 1$.

Inserting this parametrization in the Stokes vector in Eq. (9) (neglecting the small W-exchange effects for clarity) the results are:

$$S_1 = \frac{-2\xi |E_{\rm SD}||E_{\rm LD}| \sin(\delta_{\rm dyn} - \beta)}{|\mathcal{E}|^2 + |\mathcal{M}|^2},$$

$$S_2 = \frac{-2|E_{\rm SD}|^2 - 2\xi|E_{\rm SD}||E_{\rm LD}|\cos(\delta_{\rm dyn} - \beta)}{|\mathcal{E}|^2 + |\mathcal{M}|^2}, \tag{17}$$
$$S_3 = \frac{\xi^2|E_{\rm LD}|^2 + 2\xi|E_{\rm SD}||E_{\rm LD}|\cos(\delta_{\rm dyn} - \beta)}{|\mathcal{E}|^2 + |\mathcal{M}|^2}.$$

And the CP asymmetry is ($A_{\rm CP} = (\Gamma(\overline{B^0}) - \Gamma(B^0))/(\Gamma(\overline{B^0}) + \Gamma(B^0))$)

$$A_{\rm CP} = \frac{4\xi|E_{\rm SD}||E_{\rm LD}|\sin\delta_{\rm dyn}\sin\beta}{|\mathcal{E}|^2 + |\mathcal{M}|^2 + |\overline{\mathcal{E}}|^2 + |\overline{\mathcal{M}}|^2}. \tag{18}$$

The results are shown in Fig. (2) for the CP asymmetry and in Fig. (3) for the Stokes vector, respectively. The central values used for the weak CKM phases are $\beta = 23^\circ$ and $\gamma = 59^\circ$.

The CP asymmetry in Fig. (2) ranges from -22% for $\xi = -1$ to 26% for $\xi = 1$ and vanishes at $\xi = 0$. Even for $|\xi| \approx 0.3$ which corresponds to a long-distance contribution of 3% in the decay rate the asymmetry is still large: $|A_{\rm CP}| \approx 10\%$.

The effects of the long distance contribution to the Stokes vector are also large. The component S_1 (solid line) in Fig. (3) has a value around 0.7 for $\xi = -1$ and around -0.5 for $\xi = 1$ to be compared to $S_1 = 0$ at $\xi = 0$. The component S_3 (dashed line) is small for $\xi < 0$ but approaches 0.35 for $\xi = 1$. The component S_2 (dotted line) is plotted for completeness.

The Stokes vector components S_1 and S_3 are observable in the decay $\overline{B^0} \to \rho^0\gamma^* \to \pi^+\pi^-e^+e^-$ according to [2]

$$\frac{d\Gamma}{ds_l\, d\phi} \sim 1 - (\Sigma_1(s_l)\, \sin 2\phi + \Sigma_3(s_l)\, \cos 2\phi)\,, \tag{19}$$

where $\Sigma_1(0)$ and $\Sigma_3(0)$ are proportional to S_1 and S_3, respectively. ϕ is the angle between the dipion and the dilepton plane.

To determine the magnitude of Σ_1 and Σ_3 we follow reference [10]. There, the decay $\overline{B^0} \to \pi^+\pi^-e^+e^-$ is constructed under the assumption that the pion pair is produced at the ρ^0 resonance in a narrow width approximation. Additional to the short-distance contribution due to $\mathcal{O}_7$ in the Hamiltonian (Eq. (1)) the operators $\mathcal{O}_9$ and $\mathcal{O}_{10}$ have to be included. They dominate the decay rate in the region of higher dilepton mass s_l. We use in our calculation the Wilson coefficients $c_7 = -0.315$, $c_9 = 4.224$ and $c_{10} = -4.642$.

The resulting differential decay rate is written in a compact form in Eq. (3.7) of [10]. The effects of the long-distance contributions to this decay are incorporated by modifying the form factors $g_+(s_l)$ and $g_-(s_l)$ ($q^2 \equiv s_l$) in Eqs. (2.16) and (2.18) of [10]: [2]

$$g_+(s_l) \;\to\; g_+(s_l) - \xi g_{\rm LD}(s_l), \tag{20}$$
$$g_-(s_l) \;\to\; g_-(s_l) + \xi g_{\rm LD}(s_l), \tag{21}$$

where

$$g_{\rm LD}(0) = \frac{V_{cb}V_{cd}^*}{V_{tb}V_{td}^*}\frac{f_{\rho^0 D^+ D^-}\, g_{B^0 D^+ D^-}}{4c_7 m_{D^+}^2 (m_b - m_d)} F(m_{B^0}^2, m_{\rho^0}^2), \tag{22}$$

[2]For the form factors, we have used the parametrization in Table IV of [10]. However, the normalization has been updated to take account of the value $g_+(0)|_{B^-\to\rho^-} = -T_1^{B^-\to\rho^-}(0) = -0.27$ [1] instead of the value -0.18 used in [10]. Note that $g_\pm(0) \equiv g_\pm(0)|_{B^0\to\rho^0} = \frac{1}{\sqrt{2}} g_\pm(0)|_{B^-\to\rho^-}$.

and

$$\frac{g_{\rm LD}(s_l)}{g_{\rm LD}(0)} = G(m_{B^0}^2, s_l)\, F_{\rm em}^D(s_l). \tag{23}$$

The function $G(m_{B^0}^2, s_l)$ describes the effects due to the triangle graph in Fig. (1) (assuming, for simplicity, scalar external particles):

$$\begin{aligned}
G(m_{B^0}^2, s_l) &= \left[1 - \frac{f_c\,\theta(c-1) + f_c'\,\theta(1-c)}{f_a}\right] \left(1 - \frac{s_l}{m_{B^0}^2}\right)^{-1}, \qquad (24)\\
f_c &= -\left(\ln\left(\sqrt{c} + \sqrt{c-1}\right) - i\frac{\pi}{2}\right)^2,\\
f_c' &= \arcsin^2\left(\sqrt{c}\right),\\
c &= \frac{s_l}{4m_{D^+}^2}.
\end{aligned}$$

and f_a as in Eq. (12). The factor $F_{\rm em}^D(s_l)$ is the electromagnetic form factor of the D meson in vector dominance approximation:

$$\begin{aligned}
F_{\rm em}^D(s_l) &= \frac{3}{2}\frac{1}{1 - \frac{s_l}{m_{\rho^0}^2} - i\frac{\Gamma_{\rho^0}}{m_{\rho^0}}\left(1 - \frac{4m_\pi^2}{s_l}\right)^{\frac{3}{2}} \theta(s_l - 4m_\pi^2)} \qquad (25)\\
&\quad -\frac{1}{2}\frac{1}{1 - \frac{s_l}{m_\omega^2} - i\frac{\Gamma_\omega}{m_\omega}\theta(s_l - 9m_\pi^2)}
\end{aligned}$$

Integrating all variables but ϕ and s_l in the differential decay rate yields Eq. (19). The results for $\Sigma_1(s_l)$ and $\Sigma_3(s_l)$ are shown in Fig. (4) and Fig.(5), respectively. Comparing the Stokes parameters S_1 to $\Sigma_1(0)$ and S_3 to $\Sigma_3(0)$ shows that they differ only by a factor of roughly 2. Both, $\Sigma_1(s_l)$ and $\Sigma_3(s_l)$ can be dominated in the region $s_l < 2\,GeV^2$ by the proposed long-distance effect, depending on the choice of the parameter ξ. The branching ratio of $\overline{B^0} \to \rho^0\gamma^* \to \pi^+\pi^-e^+e^-$ in the region $s_l < 2\,GeV^2$ is found to be $(1.9,\ 1.3,\ 1.8) \times 10^{-8}$ for $\xi = (+\frac{1}{2},\ 0,\ -\frac{1}{2})$. For $s_l > 2\,GeV^2$ the branching ratio is 2.7×10^{-8}, almost independent of ξ.

3 Remarks on Stokes Parameter for $\overline{B^0} \to \overline{K^*}\gamma$

Using a description for the short-distance amplitude in the decay $\overline{B^0} \to \overline{K^*}\gamma$ similar to that of Eq. (3), it immediately follows, as in pure short-distance $\overline{B^0} \to \rho^0\gamma$, that $A_{\rm CP} = 0$, $S_{1,3} = 0$, $S_2 = -1$. To embed the long-distance model in the decay $\overline{B^0} \to \overline{K^*}\gamma$ we used the same definitions as in $\overline{B^0} \to \rho^0\gamma$ and made the following modifications, assuming $SU(3)$-symmetry: The vertices $\overline{B^0} \to D^+D^-$ and $\rho^0 D^+D^-$ change to $\overline{B^0} \to D^+D_s^-$ and $\overline{K^*}D^+D_s^-$, respectively. In the CKM matrix elements exchange $d \leftrightarrow s$ and align the form factors to the values found in the tables of $B \to \overline{K^*}$ decays [6].

The coupling $g_{B^0D^+D_s^-}$ can be calculated from the branching ratio $Br(\overline{B^0} \to D^+D_s^-) = 9.6 \times 10^{-3}$ [11], and $SU(3)$-symmetry gives $f_{\overline{K^*}D^+D_s^-} = \sqrt{2}\, f_{\rho^0 D^+D^-}$.

Since there is no relative weak phase (up to order λ^4) in $\overline{B^0} \to \overline{K^*}\gamma$ even after including the proposed long-distance contribution, the CP-asymmetry is $A_{\rm CP} = 0$ for all values of ξ. However,

due to the absorptive part of the triangle graph a strong (dynamical) phase is still present. In fact, it is essentially as large as in $\overline{B^0} \to \rho^0\gamma$: $\delta_{\rm dyn} \approx 97^\circ$. The presence of this phase can be seen in the Stokes vector components which are shown in Fig. (6). For $\xi \neq 0$ the components S_1 and S_3 display a significant deviation from zero.

The Stokes vector components S_1 and S_3 can be detected in $\overline{B^0} \to \overline{K^*}\gamma^* \to \pi^+K^-e^+e^-$ [10] in the differential decay rate:

$$\frac{d\Gamma}{ds_l\, d\phi} \sim 1 - (\Sigma_1(s_l)\, \sin 2\phi + \Sigma_3(s_l)\, \cos 2\phi)\,, \tag{26}$$

which is derived in a way analogous to that in the decay $\overline{B^0} \to \pi^+\pi^-e^+e^-$ described before. The results for Σ_1 and Σ_3 are shown in Figs. (7) and (8), respectively. Again, in the lower region of s_l the long-distance contribution can play an important role depending on the parameter ξ. The branching ratio in the domain $s_l < 2\,GeV^2$ is (0.8, 0.6, 0.9) $\times\, 10^{-6}$ for $\xi = (+\frac{1}{2},\, 0,\, -\frac{1}{2})$, while for $s_l > 2\,GeV^2$, the corresponding value is 0.9×10^{-6}, essentially independent of ξ.

4 Summary

We have examined a long-distance contribution to the decay $\overline{B^0} \to \rho^0\gamma$, which induces a non-zero CP-violating asymmetry, $A_{\rm CP} \neq 0$. At the same time, the Stokes parameters S_1, S_3 of the photon acquire non-zero values that can be detected in the correlation of the $\pi^+\pi^-$ and e^+e^- planes in the decay $\overline{B^0} \to \rho^0\gamma^* \to \pi^+\pi^-e^+e^-$. The same long-distance mechanism has been examined in the case of $\overline{B^0} \to \overline{K^*}\gamma$. Although $A_{\rm CP}$ remains zero in this case, significant effects due to the Stokes parameters S_1, S_3 are predicted in the correlation of the hadron and lepton planes in the Dalitz pair process $\overline{B^0} \to \overline{K^*}\gamma^* \to \pi^+K^-e^+e^-$.

References

[1] M. Beyer, D. Melikhov, N. Nikitin and B. Stech, Phys. Rev. D **64**, 094006 (2001).

[2] L. M. Sehgal and J. van Leusen, Phys. Rev. Lett. **83**, 4933 (1999).

[3] B. Grinstein, D. Pirjol, Phys. Rev. D **62**, 093002 (2000); A. Ali, A. Y. Parkhomenko Eur. Phys. J. C **23**, 89 (2002).

[4] D. Choudhury and J. Ellis, Phys. Lett. B **433**, 102 (1998); W. Liu, B. Zhang and H. Zheng, Phys. Lett. B **461**, 295 (1999).

[5] M. Ciuchini, R. Contino, E. Franco, G. Martinelli and L. Silvestrini, Nucl. Phys. B **512** 3 (1998); *ibid.* B **531** 656 (1998); A. J. Buras and L. Silvestrini, Nucl. Phys. B **569** 3 (2000).

[6] M. Wirbel, B. Stech and C. Bauer, Z. Phys. C **29**, 637 (1985); D. Melikhov, Phys. Rev. D **53**, 2460 (1996); D **56**, 7089 (1997); M. Beyer, D. Melikhov, Phys. Lett. B **452**, 121 (1999); D. Melikhov, B. Stech, Phys. Rev. D **62**, 014066 (2000).

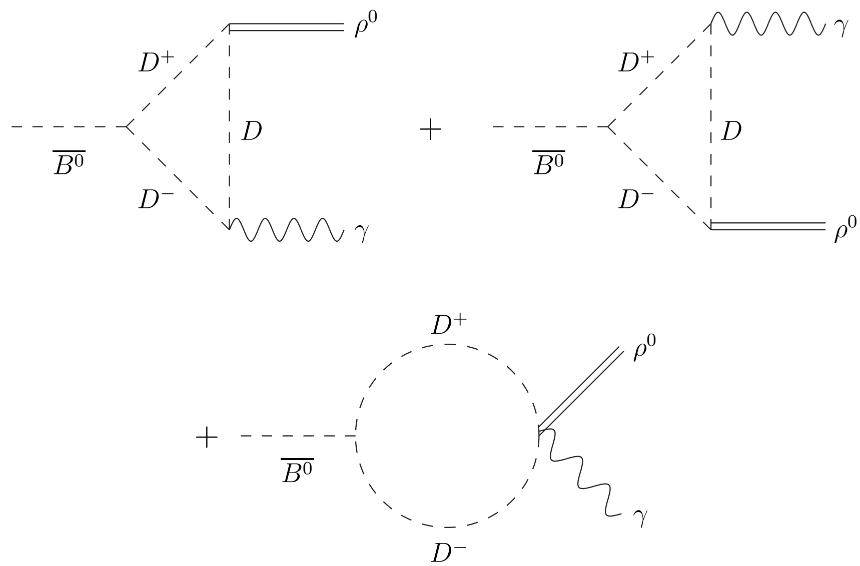

Figure 1: Proposed long-distance contribution for $\overline{B^0} \to \rho^0\gamma$: triangle, crossed and sea-gull graph

[7] J. Pestieau, C. Smith and S. Trine, Int. J. Mod. Phys. A **17**, 1355 (2002); C. Smith, Ph. D. dissertation, Appendix A, Université Catholique de Louvain, Louvain-la-Neuve, May 2002; see also L. M. Sehgal, Phys. Rev. D **7**, 3303 (1973).

[8] T. Browder, talk at *Lepton & Photon 2003*, Batavia, Illinois, 2003.

[9] Babar Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **91**, 131801 (2003).

[10] F. Krüger, L. M. Sehgal, N. Sinha and R. Sinha, Phys. Rev. D **61**, 114028 (2000); *ibid.* **63**, 019901(E) (2000).

[11] M. Neubert and B. Stech, in "Heavy Flavours", $2^{\underline{\text{nd}}}$ Edition, edited by A. J. Buras and M. Lindner (World Scientific, Singapore); hep-ph/9705292.

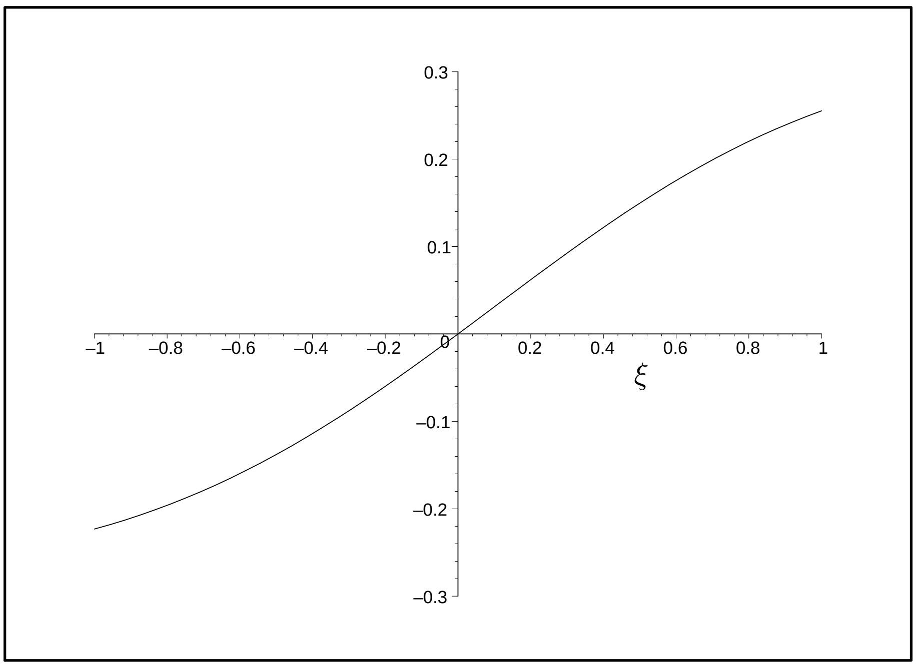

Figure 2: The CP asymmetry as a function of the scale parameter ξ of the long distance contribution in $B \to \rho^0\gamma$.

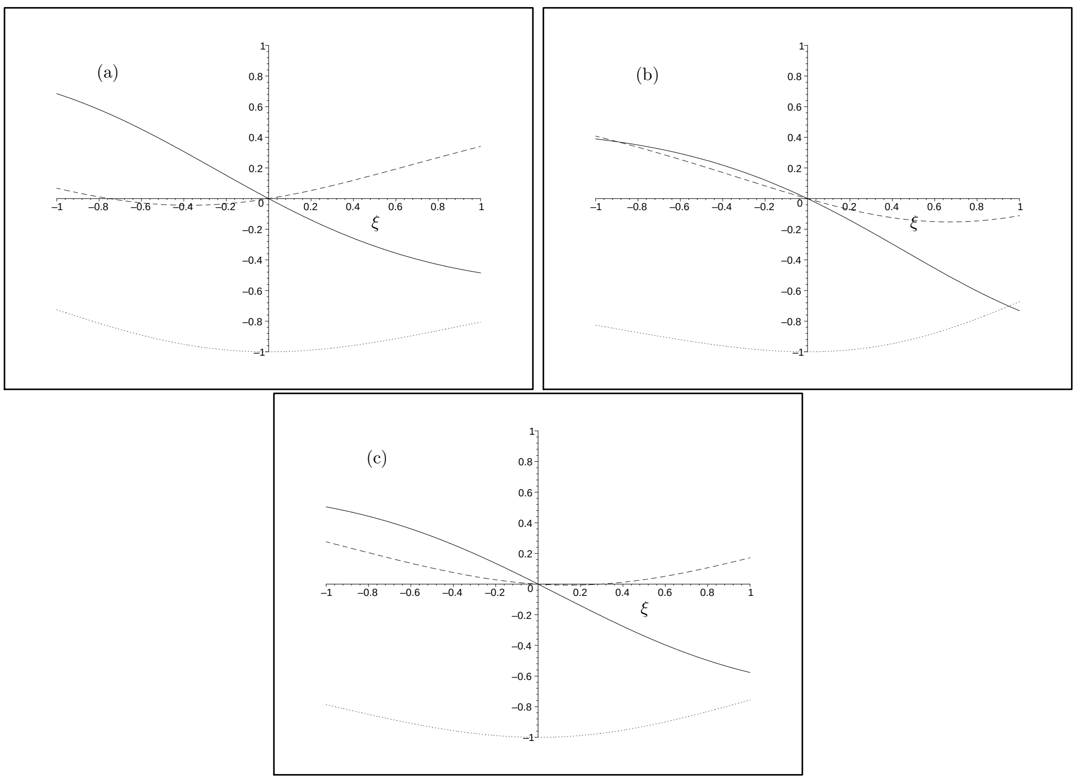

Figure 3: The Stokes vector $\vec{S}$ as a function of the scale parameter ξ of the long distance contribution in (a) $\overline{B^0} \to \rho^0\gamma$, (b) $B^0 \to \rho^0\gamma$ and (c) an untagged mixture of $\overline{B^0}/B^0 \to \rho^0\gamma$. The solid line describes the S_1 component, the dotted line the S_2 component and the dashed line the S_3 component.

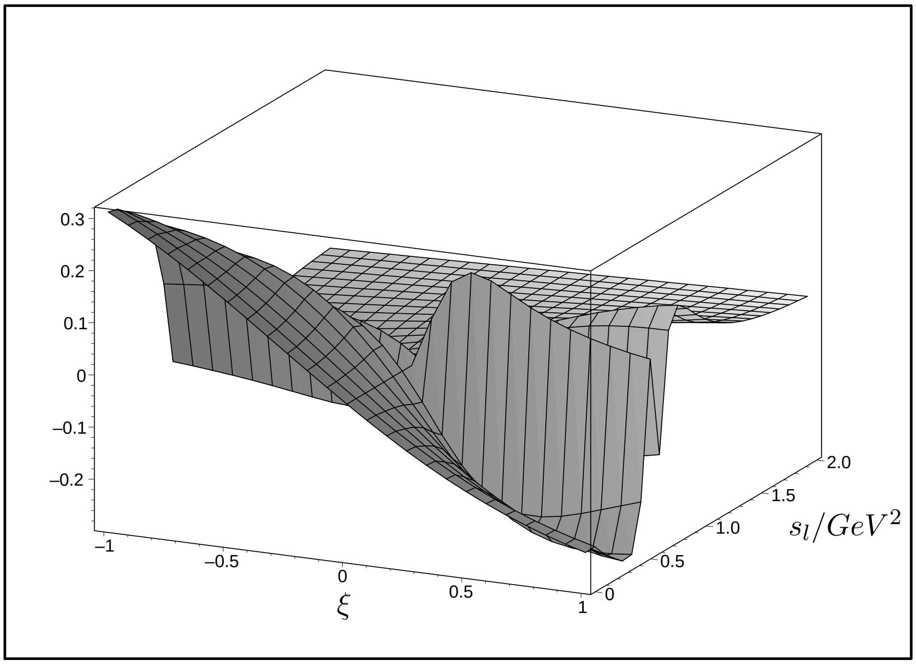

Figure 4: The component Σ_1 as a function of the scale parameter ξ of the long distance contribution and the dilepton energy s_l in $\overline{B^0} \to \pi^+\pi^- e^+ e^-$.

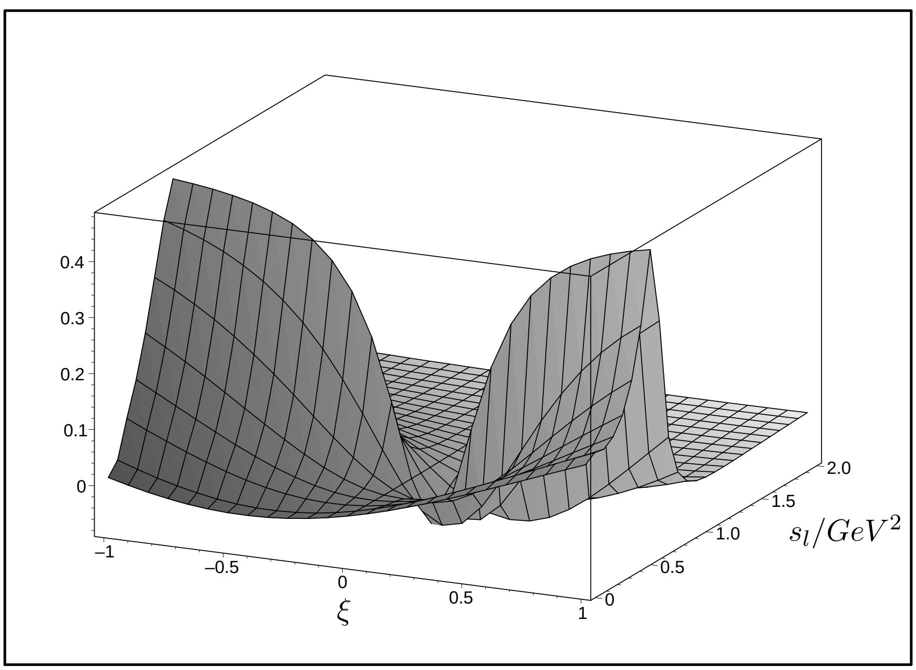

Figure 5: The component Σ_3 as a function of the scale parameter ξ of the long distance contribution and the dilepton energy s_l in $\overline{B^0} \to \pi^+\pi^- e^+ e^-$.

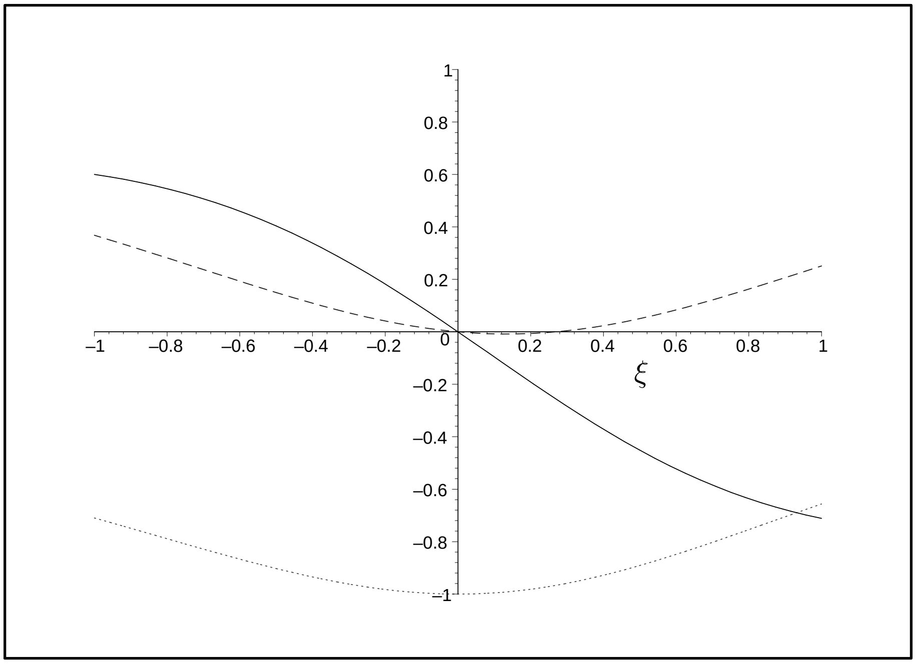

Figure 6: The Stokesvector $\vec{S}$ as a function of the scale parameter ξ of the long distance contribution in $\overline{B^0} \to K^*\gamma$. The solid line describes the S_1 component, the dotted line the S_2 component and the dashed line the S_3 component.

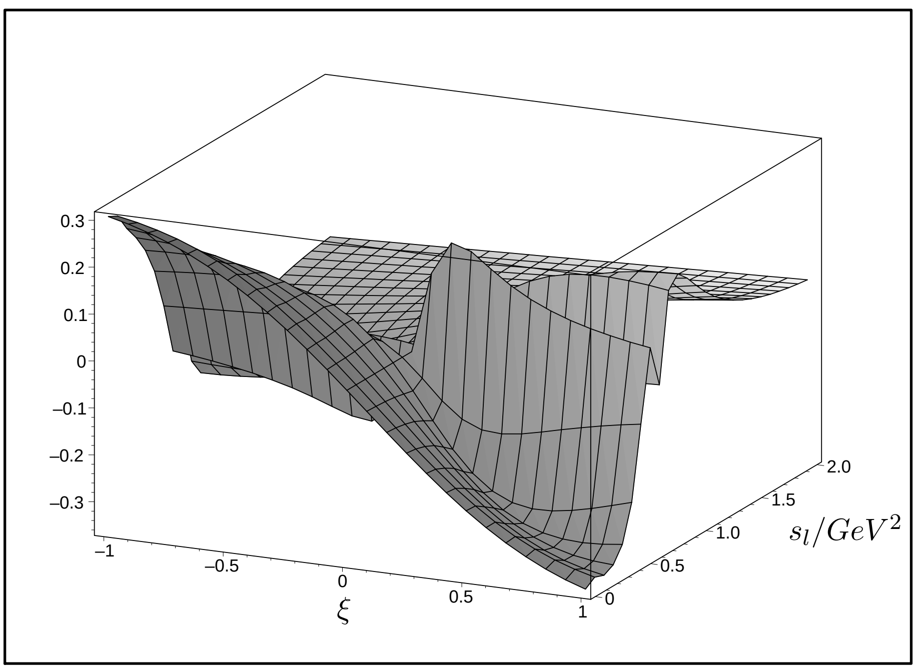

Figure 7: The component Σ_1 as a function of the scale parameter ξ of the long distance contribution and the dilepton energy s_l in $\overline{B^0} \to \pi^+ K^- e^+ e^-$.

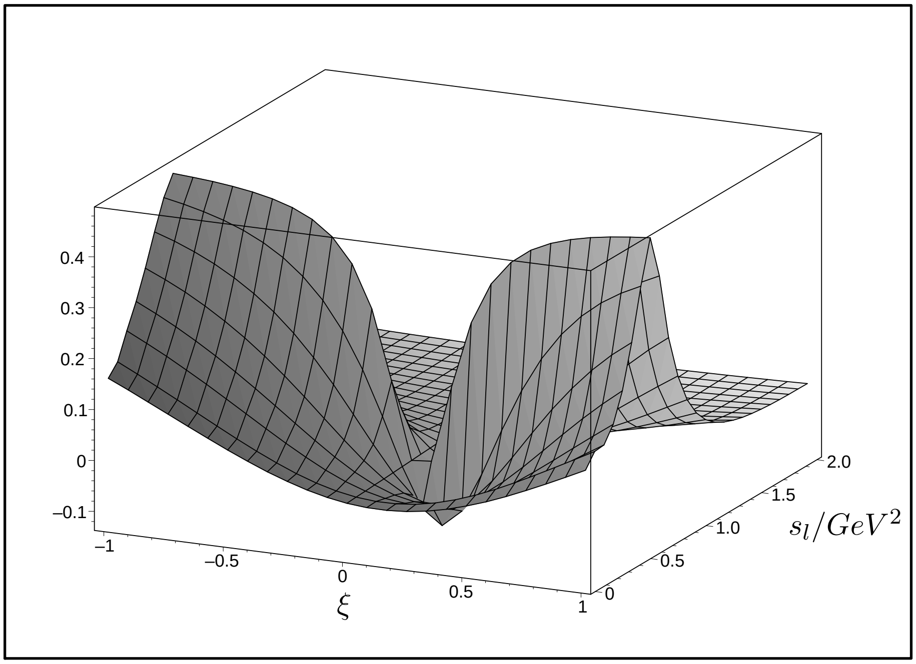

Figure 8: The component Σ_3 as a function of the scale parameter ξ of the long distance contribution and the dilepton energy s_l in $\overline{B^0} \to \pi^+ K^- e^+ e^-$.